A Fuzzy-based Handover System for Avoiding Ping-Pong Effect in Wireless Cellular Networks

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Abstract

Many handover algorithms are proposed in the literature. However, to make a better handover and keep the QoS in wireless networks is very difficult. In this paper, we propose a new handover system based on fuzzy logic. The proposed system uses 3 parameters for handoff decision: the change of signal strength of the present Base Station (BS), signal strength from the neighbor BS, and the distance between Mobile Station (MS) and BS. The performance evaluation via simulations shows that proposed system can avoid ping-pong effect and has a good handover decision.

1 Introduction

During the last few years wireless multimedia networks have been a very active research area [1,2]. The QoS support for future wireless networks is a very important problem. To guarantee the QoS, a good handover strategy is needed in order to balance the call blocking and call dropping for providing the required QoS [3,4]. In the future, the wireless networks will adopt a micro/pico cellular architecture. However, smaller cell size naturally increases the number of handoffs a Mobile Station (MS) is expected to make [5,6].

Many metrics have been used to support handover decisions, including Received Signal Strength (RSS), Signal to Interference Ratio (SIR), distance between the mobile and BS, traffic load, and mobile velocity, where RSS is the most commonly used one. The conventional handover decision compares the RSS from the serving BS with that from one of the target BSs, using a constant handover threshold value (handover margin). However, the fluctuations of signal strength associated with shadow fading cause the ping-pong effect [7].

Many investigations have addressed handover algorithms for cellular communication systems. However, it is essentially complex to make handover decision considering multiple criteria. Sometimes, the trade-off of some criteria should be considered. Therefore, heuristic approaches based on Neural Networks (NN), Genetic Algorithms (GA) and Fuzzy Logic (FL) can prove to be efficient for wireless networks [8,9,10,11]. In [10], a multi-criteria handover algorithm for next generation tactical communication systems is introduced. The handover metrics are: RSS from current and candidate base transceivers, ratio of used soft capacity to the total soft capacity of base transceivers, the relative directions and speeds of the base transceivers and the mobile node. In [11], a handover algorithm is proposed to support vertical handover between heterogeneous networks. This is

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achieved by incorporating the mobile IP principles in combination with FL concepts utilizing different handover parameters.

In this paper, in different from other works we use Random Walk (RW) model and FL to design a new handover system, which is able to avoid ping-pong effect and has a good handover decision. The structure of this paper is as follows. In Section 2, we present the handover decision problem. In Section 3, we give a brief introduction of RW model. In Section 4, we introduce the proposed system. In Section 5, we discuss the simulation results. Finally, some conclusions are given in Section 6.

2 Handover Decision Problem

Handoffs which are consistently both accurate and timely can result in higher capacity and better overall link quality than what is available with today systems [12,13]. Now with increasing demands for more system capacity, there is a trend toward smaller cells, also known as microcells. Handoffs are more critical in systems with smaller cells, because for a given average user speed, handoff rates tend to be inversely proportional to cell size [5].

The main objectives of handover are link quality maintenance, interference reduction and keeping the number of handoffs low. Also, a handover algorithm should initiate a handoff if and only if the handoff is necessary. The accuracy of a handover algorithm is based on how the algorithm initiates the handover process. The timing of the handoff initiation is also important. There can be deleterious effects on link quality and interference if the initiation is too early or too late. A timely handover algorithm is one which initiates handoffs neither too early nor too late.

Because of large-scale and small-scale fades are frequently encountered in mobile environment, it is very difficult for handover algorithm to make an accurate and timely decision. Handover algorithms operating in real time have to make decisions without the luxury of repeated uncorrelated measurements or the future signal strength information. It should be noted that some of handover criteria information can be inherently imprecise, or the precise information is difficult to obtain. For this reason, we propose a FL-based approach, which can operate with imprecision data and can model nonlinear functions with arbitrary complexity.

3 RW Model

The Monte Carlo (MC) method is a technique that uses random numbers and probability to solve problems. It is often used when the model is complex, nonlinear, or involves more than just a couple uncertain parameters.

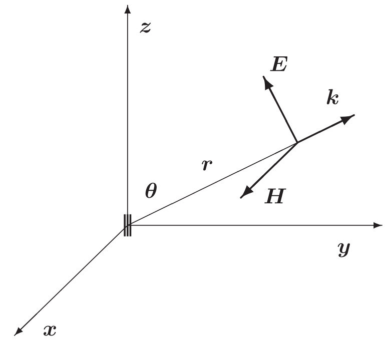

Figure 1. Dipole antenna.

The MC method can be used for analyzing uncertainty propagation, where the goal is to determine how random variation, lack of knowledge, or error affects the sensitivity, performance, or reliability of the system that is being modeled. MC simulation is categorized as a sampling method because the inputs are randomly generated from probability distributions to simulate the process of sampling from an actual population. The data generated from the simulation can be represented as probability distributions (or histograms) or converted to error bars, reliability predictions, tolerance zones, and confidence intervals.

We use the MC method for realizing RW model. We consider a 2-dimensional field. The initial position is considered as a origin point and we decided based on MC method the moving pattern for each walk. If we consider n user movements and the angle θ and distance d for each walk are generated by general or Gaussian distribution, when the movement changes in x and y directions are Δx and Δy, respectively, then we have the following relations.

$$\Delta x_n = d_n cos\theta_n, \quad \Delta y_n = d_n sin\theta_n \tag{1}$$

$$x_{n+1} = x_n + \Delta x_n, \quad y_{n+1} = y_n + \Delta y_n \tag{2}$$

The Base Station (BS) position can be expressed by Cartesian coordinates. By converting Cartesian coordinates to polar ones, we can calculate the angle θ.

We consider that in the cellular system each cell has a hexagonal shape and the BS is located in the center of the cell. The angle θ between Dipole Antenna (DA) and vector $\boldsymbol{r}$ is $D(\theta) = \sin\theta$. If we consider the transmission power as W, the antenna radiation intensity can be calculated as follows:

$$\boldsymbol{E} = \sqrt{45W} \sin\theta \frac{e^{-j\kappa r}}{r^n} \boldsymbol{u_0} \tag{3}$$

where, the DA gain is $G = 1.5$ and $\boldsymbol{u_0}$ is the unit vector that shows DA direction. In Fig. 1 $\boldsymbol{u_0}$ is in Z direction.

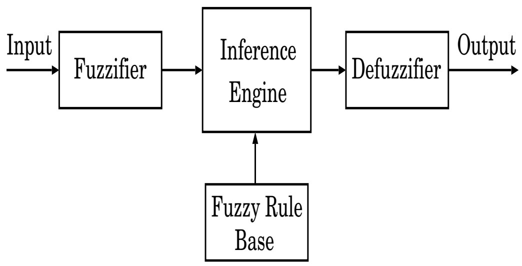

Figure 2. FLC structure.

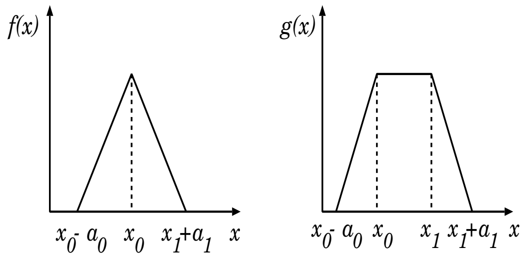

Figure 3. Membership function shapes.

In Eq.(3), when $\theta = 90°$, the E value will be maximal in horizontal direction. However, in real situations, the direction of antenna is in not set 90° in order to cover better the cell area. If we consider the beam tilting angle and the distance, the E can be calculated by the following equation.

$$\boldsymbol{E} = \sqrt{45W}\sin(\theta - \phi)\frac{e^{-j\kappa r}}{r^n}\boldsymbol{u_0} \tag{4}$$

4 Proposed System Model

The Fuzzy Logic Controller (FLC) is the main part of the proposed system and its basic elements are shown in Fig. 2. They are the fuzzifier, inference engine, Fuzzy Rule Base (FRB) and defuzzifier. As shown in Fig. 3, as membership functions we use triangular and trapezoidal membership functions because they are suitable for real-time operation [14].

In Fig. 3, x_0 in $f(.)$ is the center of triangular function, $x_0(x_1)$ in $g(.)$ is the left (right) edge of trapezoidal function, and $a_0(a_1)$ is the left (right) width of the triangular or trapezoidal function.

The proposed fuzzy model is shown in Fig. 4. In this system, the $Node\_B$ shows the wireless transmitter and receiver of BS, RNS indicates Radio Network System, POTLC stands for Post Test-Loop Controller and PRTLC for Pre Test-Loop Controller.

The input parameters for FLC are: Change of the Signal Strength of Present BS (*CSSP*), Signal Strength from the Neighbor BS (*SSN*), and the distance of MS from BS (*DMB*), while the output linguistic parameter is Handover Decision (*HD*).

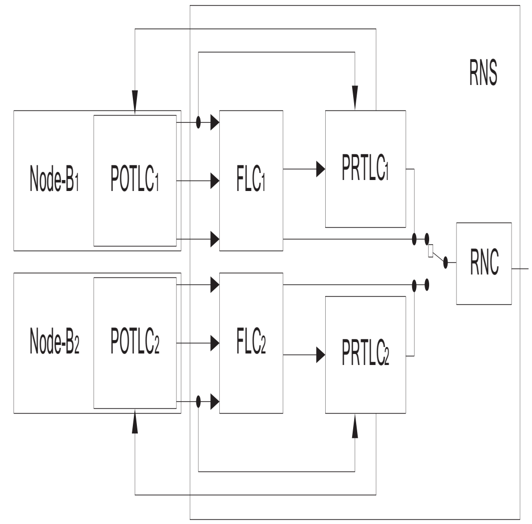

Figure 4. System model.

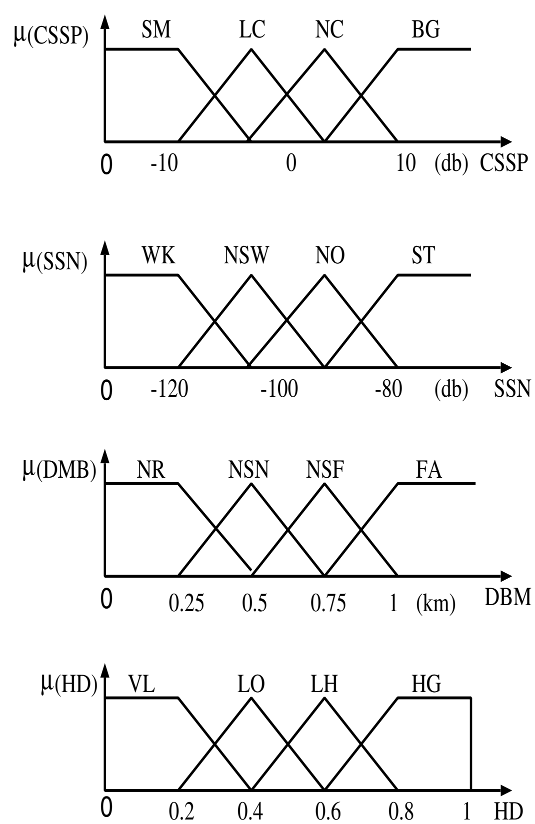

Figure 5. Membership functions.

Table 1. FRB.

Rules	CSSP	SSN	DMB	HD	Rules	CSSP	SSN	DMB	HD
1	SM	WK	NR	LO	33	NC	WK	NR	VL
2	SM	WK	NSN	LO	34	NC	WK	NSN	VL
3	SM	WK	NSF	LH	35	NC	WK	NSF	VL
4	SM	WK	FA	LH	36	NC	WK	FA	LO
5	SM	NSW	NR	LO	37	NC	NSW	NR	VL
6	SM	NSW	NSN	LO	38	NC	NSW	NSN	VL
7	SM	NSW	NSF	LH	39	NC	NSW	NSF	VL
8	SM	NSW	FA	LH	40	NC	NSW	FA	LO
9	SM	NO	NR	LH	41	NC	NO	NR	VL
10	SM	NO	NSN	HG	42	NC	NO	NSN	LO
11	SM	NO	NSF	HG	43	NC	NO	NSF	LO
12	SM	NO	FA	HG	44	NC	NO	FA	LH
13	SM	ST	NR	HG	45	NC	ST	NR	LH
14	SM	ST	NSN	HG	46	NC	ST	NSN	LH
15	SM	ST	NSF	HG	47	NC	ST	NSF	HG
16	SM	ST	FA	HG	48	NC	ST	FA	HG
17	LC	WK	NR	VL	49	BG	WK	NR	VL
18	LC	WK	NSN	VL	50	BG	WK	NSN	VL
19	LC	WK	NSF	LO	51	BG	WK	NSF	VL
20	LC	WK	FA	LO	52	BG	WK	FA	VL
21	LC	NSW	NR	LO	53	BG	NSW	NR	VL
22	LC	NSW	NSN	LO	54	BG	NSW	NSN	VL
23	LC	NSW	NSF	LO	55	BG	NSW	NSF	VL
24	LC	NSW	FA	LH	56	BG	NSW	FA	LO
25	LC	NO	NR	LH	57	BG	NO	NR	VL
26	LC	NO	NSN	LH	58	BG	NO	NSN	VL
27	LC	NO	NSF	HG	59	BG	NO	NSF	LO
28	LC	NO	FA	HG	60	BG	NO	FA	LO
29	LC	ST	NR	LH	61	BG	ST	NR	VL
30	LC	ST	NSN	HG	62	BG	ST	NSN	VL
31	LC	ST	NSF	HG	63	BG	ST	NSF	LO
32	LC	ST	FA	HG	64	BG	ST	FA	LO

The system operation is as follows. First, after receiving the control information from MS, the POTLC check the quality of the signal. If the signal strength is still good enough the handover is not carried out. If the signal strength is lower than a predefined value, then based on *CSSP*, *SSN* and *DMB*, the FLC decides whether the handover is necessary or not. If the handover is not necessary the control is returned to the present BS, otherwise another check of the signal strength is carried out in PRTLC and the present signal strength is compared with the previous signal strength. When the present signal strength is lower than the strength of the previous signal, the handover procedure is carried out.

The term sets of *CSSP*, *SSN* and *DMB* are defined respectively as:

$$\begin{aligned} T(CSSP) &= \{Small, Little\ Change, No\ Change, Big\} \\ &= \{SM, LC, NC, BG\}; \\ T(SSN) &= \{Weak, Not\ So\ Weak, Normal, Strong\} \\ &= \{WK, NSW, NO, ST\}; \\ T(DMB) &= \{Near, Not\ So\ Near, Not\ So\ Far, Far\} \\ &= \{NR, NSN, NSF, FA\}. \end{aligned}$$

The output linguistic parameter $T(HD)$ is defined as $\{Very\ \ Low, Low, Little\ \ High, High\} = \{VL, LO, LH, HG\}$.

The membership functions of FLC are shown in Fig. 5. The FRB forms a fuzzy set of dimensions $|T(CSSP)| \times |T(SSN)| \times |T(DMB)|$, where $|T(x)|$ is the number of terms on $T(x)$. The FRB is shown in Table 1 and has 64 rules. The control rules have the following form: IF "conditions" THEN "control action".

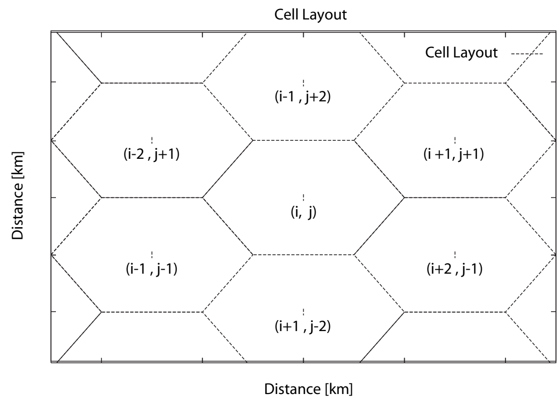

Figure 6. Cell layout.

5 Simulation Results

The cell shape is hexagonal and the coordinates of BSs are indicated as shown in Fig. 6. The BS is located in the center of the cell, the transmission antenna power is 10 W, and cell radius is 2 km. In Table 2 are shown the simulation parameters.

In Fig. 7 is showing the walking pattern for a MS when $iseed = 100$ and $nwalk = 5$, while in Fig. 8 for $iseed = 200$ and $nwalk = 10$. In Fig. 7, the MS moves in the cells: (0,0)→(2,-1)→(0,0)→(1,-2), while in Fig. 8 in the cells: (0,0)→(-1,2)→(-2,1)→(-1,2). In Fig. 7, the ping-pong effect happens, because the MS is moving in the cells boundary. While in Fig. 8, the handover process is necessary.

In Fig. 9, Fig. 10 and Fig. 11 are showing the received power from the BS(0,0), BS(2,-1)Cand BS(1,-2) when $iseed = 200$. We have also the results for $iseed = 100$, but for the sake of space will not show in this paper. As can be seen from Fig. 9, when the MS is going far from the BS the received power is decreased, while when the MS is approaching neighbor BS the received power from these BSs is increased (see Fig. 10 and Fig. 11).

For evaluation of the proposed fuzzy-based handover system, we carried out the measurement for 3 points, where the MS is in the boundary of the 3 cells. In Fig. 12 and Fig. 13 are shown the measurement points for $iseed = 100$ and $iseed = 200$, respectively. In Fig. 12, the handover should not be carried out, because we will have the ping-pong effect, while in Fig. 13 the handover is necessary because the MS is moving inside the neighbor cells.

In our system, we consider that the handover is carried out when the output value is bigger than 0.7. We assume that during the RW for each 10 km/h the signal strength is decreased 2 db. We carry out 10 times simulations and calculate the average values. The simulation results for $iseed = 100$ and $iseed = 200$ are shown in Table 3 and Table 4, respectively.

In the case when $iseed = 100$, the MS moves in the boundary of cells. Thus if the handover will be carried out, we will have the ping-pong effect. As shown in Table 3, all the average values are smaller than 0.7, therefore the proposed system can avoid the ping-pong effect.

In the case when $iseed = 200$, the MS is moving inside the neighbor cells, so the handover should be carried out 3 times. In the results of Table 4, the proposed system in all cases has done 3 handovers. This shows that the proposed system has a good handover decision.

Table 2. Simulation parameters.

Distribution Law	Gaussian Distribution
Number of Walks	5C10
Random Types	100C200
Cell Radius	1kmC2km
Transmission Power	10WC20W
Frequency	2000MHz
Transmission Antenna Beam Tilting	3°
Transmission Antenna Height	40m
Receiving Antenna Height	1.5m
Average Value for a Walk	0.6km
n	1.1

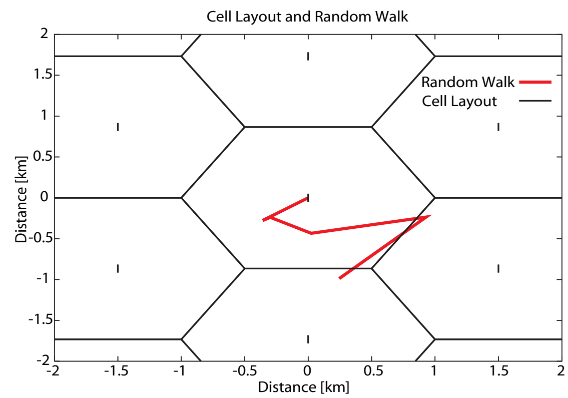

Figure 7. RW pattern for $iseed = 100$.

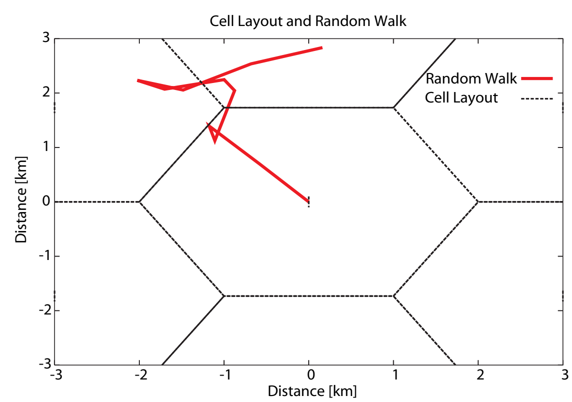

Figure 8. RW pattern for $iseed = 200$.

Table 3. Simulation results for $iseed = 100$.

Measurement Points	Point 1		Point 2		Point 3	
Speed 0 km/h						
CSSP BS	-2.710	-3.697	-1.289	0.3877	-1.189	-1.270
Neighbor BS	-93.36	-92.49	-92.77	-92.77	-94.01	-95.28
Distance	0.8858	0.9453	0.8684	0.8466	0.9367	1.0183
System Output Value	0.693	0.600	0.539	0.497	0.571	0.600
Speed 10 km/h						
CSSP BS	-2.710	-3.697	-1.289	0.3877	-1.189	-1.270
Neighbor BS	-95.36	-94.49	-94.77	-94.77	-96.01	-97.28
Distance	0.8858	0.9427	0.8684	0.8466	0.9367	1.0183
System Output Value	0.693	0.600	0.583	0.542	0.600	0.618
Speed 20 km/h						
CSSP BS	-2.710	-3.697	-1.289	0.3877	-1.189	-1.270
Neighbor BS	-97.36	-96.49	-96.77	-96.77	-98.01	-99.28
Distance	0.8858	0.9401	0.8684	0.8466	0.9367	1.0183
System Output Value	0.693	0.600	0.614	0.574	0.624	0.640
Speed 30 km/h						
CSSP BS	-2.710	-3.697	-1.289	0.3877	-1.189	-1.270
Neighbor BS	-99.36	-98.49	-98.77	-98.77	-100.0	-101.3
Distance	0.8858	0.9376	0.8684	0.8466	0.9367	1.0183
System Output Value	0.693	0.600	0.632	0.584	0.645	0.657
Speed 40 km/h						
CSSP BS	-2.710	-3.697	-1.289	0.3877	-1.189	-1.270
Neighbor BS	-101.4	-100.5	-100.8	-100.8	-102.0	-103.3
Distance	0.8858	0.9351	0.8684	0.8466	0.9367	1.0183
System Output Value	0.693	0.600	0.631	0.582	0.656	0.662
Speed 50 km/h						
CSSP BS	-2.710	-3.697	-1.289	0.3877	-1.189	-1.270
Neighbor BS	-103.4	-102.5	-102.8	-102.8	-104.0	-105.3
Distance	0.8858	0.9327	0.8684	0.8466	0.9367	1.0183
System Output Value	0.693	0.600	0.631	0.582	0.656	0.663

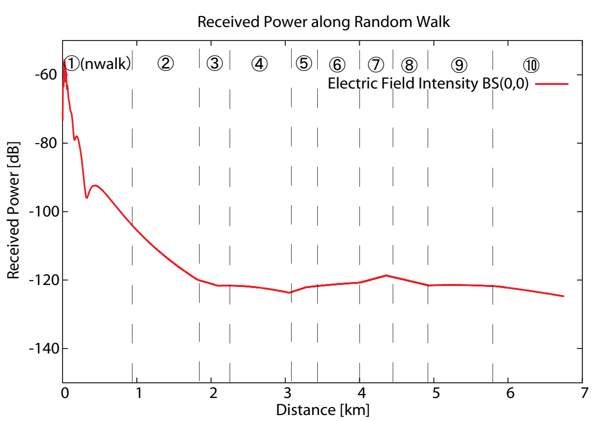

Figure 9. Received power from BS(0,0) ($iseed = 200$).

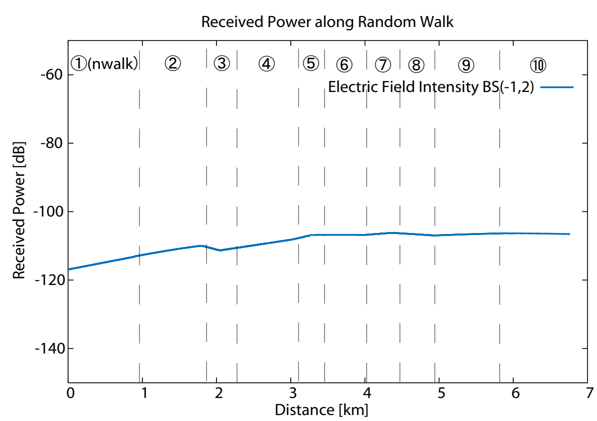

Figure 10. Received power from BS(-1,2) ($iseed = 200$).

Table 4. Simulation results for $iseed = 200$.

Measurement Points	Point 1		Point 2		Point 3	
Speed 0 km/h						
CSSP BS	−2.0149	−3.4731	−2.1681	−3.7153	−7.1891	−7.9733
Neighbor BS	−105.55	−102.07	−103.52	−96.763	−103.85	−88.422
Distance	1.9597	2.4628	1.8367	2.3453	1.8021	3.0449
System Output Value	0.645	**0.745**	0.634	**0.740**	0.692	**0.730**
Speed 10 km/h						
CSSP BS	−2.0149	−3.4731	−2.1681	−3.7153	−7.1891	−7.9733
Neighbor BS	−107.55	−104.07	−105.52	−98.763	−105.85	−90.442
Distance	1.9597	2.4628	1.8367	2.3453	1.8021	3.0449
System Output Value	0.632	**0.780**	0.634	**0.710**	0.671	**0.730**
Speed 20 km/h						
CSSP BS	−2.0149	−3.4731	−2.1681	−3.7153	−7.1891	−7.9733
Neighbor BS	−109.55	−106.07	−107.52	−100.76	−107.85	−92.422
Distance	1.9597	2.4628	1.8367	2.3453	1.8021	3.0449
System Output Value	0.616	**0.777**	0.620	**0.726**	0.633	**0.730**
Speed 30 km/h						
CSSP BS	−2.0149	−3.4731	−2.1681	−3.7153	−7.1891	−7.9733
Neighbor BS	−111.55	−108.07	−109.52	−102.76	−109.85	−94.422
Distance	1.9597	2.4628	1.8367	2.3453	1.8021	3.0449
System Output Value	0.596	**0.743**	0.597	**0.756**	0.606	**0.730**
Speed 40 km/h						
CSSP BS	−2.0149	−3.4731	−2.1681	−3.7153	−7.1891	−7.9733
Neighbor BS	−113.55	−110.07	−111.52	−104.76	−111.85	−96.422
Distance	0.3536	0.4821	0.6824	0.9047	1.3158	1.4976
System Output Value	0.576	**0.715**	0.574	**0.794**	0.591	**0.728**
Speed 50 km/h						
CSSP BS	−2.0149	−3.4731	−2.1681	−3.7153	−7.1891	−7.9733
Neighbor BS	−115.55	−112.07	−113.52	−106.76	−113.85	−98.422
Distance	0.3536	0.4821	0.6824	0.9047	1.3158	1.4976
System Output Value	0.545	**0.703**	0.553	**0.713**	0.579	**0.703**

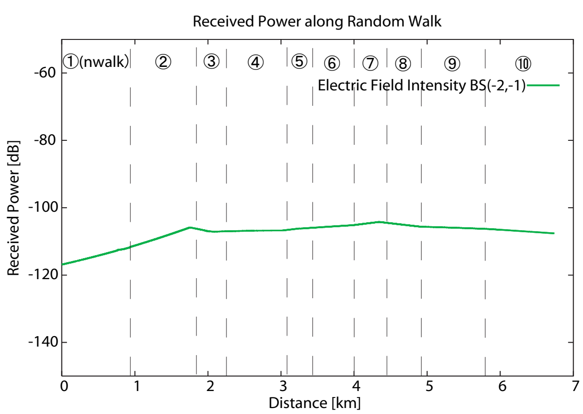

Figure 11. Received power from BS(-2,1) ($iseed = 200$).

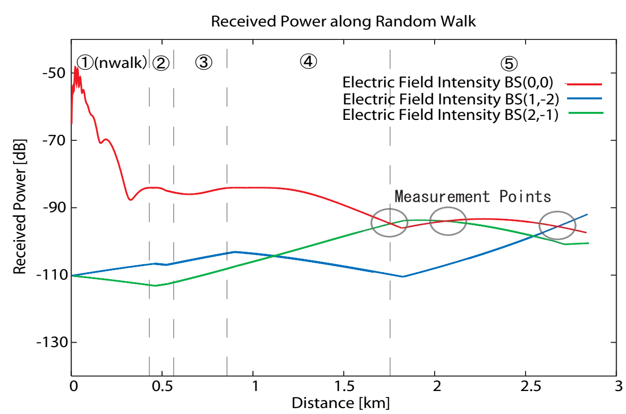

Figure 12. 3 measurement points for $iseed = 100$.

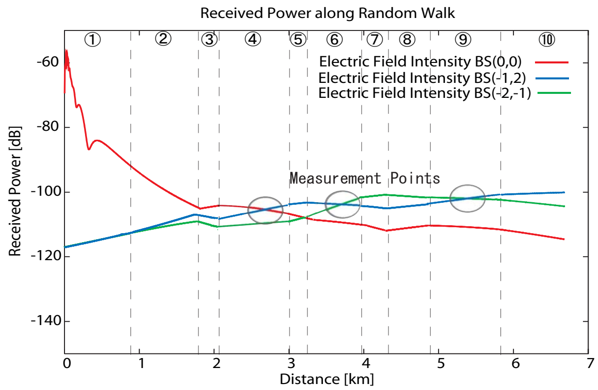

Figure 13. 3 measurement points for $iseed = 200$**.**

6 Conclusions

Many investigations have addressed handover algorithms for cellular communication systems. However, it is essentially complex to make handover decision considering multiple criteria. Sometimes, the trade-off of some criteria should be considered.

Because of large-scale and small-scale fades are frequently encountered in mobile environment, it is very difficult for handover algorithm to make an accurate and timely decision. Handover algorithms operating in real time have to make decisions without the luxury of repeated uncorrelated measurements. Some of handover criteria information can be inherently imprecise, or the precise information is difficult to obtain. For this reason, we proposed a FL-based approach, which can operate with imprecision data and can model nonlinear functions.

In this paper, we proposed a handover system using RW model and FL. The proposed system can avoid the ping-pong effect and has a good handover decision.

In the future, we would like to compare the performance of the proposed system with other non-fuzzy-based handover algorithms.

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